REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-05-

0053

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		01 Jun 2001 - 30 Nov 2001 FINAL

4. TITLE AND SUBTITLE
(Theme 2) Materials, Processing and Quality Control for High Performance Coated High Temperature Superconducting Conductors

5. FUNDING NUMBERS
61102F
2308/TA

6. AUTHOR(S)
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
4015 WILSON BLVD
SUITE 713
ARLINGTON VA 22203

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-01-1-0391

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The success of high temperature superconductor technology in the efficient use, generation, transmission, and storage of electrical energy is determined by the performance of the coated conductor and by the ability to fabricate it in long lengths at a reasonable cost. Our program on materials and processing of coated high temperature superconducting conductors has had two components in the past year: 1) improving the Jc by introducing effective pinning centers to increase the interlayer coupling and reduce the compound anisotropy by cation substitution and introduction of nano-particles; and 2) electroplated Ni layer on textured Cu substrate for Cu- based HTS coated conductors.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NE- DR. Weinstock

NA

JAN 10 2005

"Materials, Processing and Quality Control for High Performance Coated High Temperature Superconducting Conductors"

AFOSR-F49620-01-1-0391

Final ~~Annual~~ Report for December 1, 2003, to November 30, 2004

C.W. Chu and K. Salama

The success of high temperature superconductor technology in the efficient use, generation, transmission, and storage of electrical energy is determined by the performance of the coated conductor and by the ability to fabricate it in long lengths at a reasonable cost. Our program on materials and processing of coated high temperature superconducting conductors has had two components in the past year: 1) improving the J_c by introducing effective pinning centers to increase the interlayer coupling and reduce the compound anisotropy by cation substitution and introduction of nano-particles; and 2) electroplated Ni layer on textured Cu substrate for Cu-based HTS coated conductors. Progress in each of these areas is summarized below.

1 Introduction of Effective Pinning Centers

Cuprate superconductors are Type-II superconductors that have magnetic fluxoids form inside the sample when a magnetic field exceeds its lower critical field. They exhibit a layered structure with an alternate stacking of active blocks and charge-reservoir blocks. Consequently, they display a strong anisotropy and a weak pinning force and their critical current density (J_c) in general degrades rapidly in a magnetic field. For promoting practical application of high T_c superconductors, it is necessary to improve the flux pinning properties of these materials.

Among the various methods employed for increasing the J_c and the linear defects and enhancing the pinning force, chemical doping by cation substitution is a known effective method that can increase the defects and enhance the J_c significantly. It has been pointed out [1] that among different types of defects such as dislocation, grain boundaries, surface corrugations, and anti-phase boundaries, the edge and screw dislocation are the linear defects that provide the strong pinning responsible for the high critical currents observed in these thin films.

We propose to improve the J_c by introducing effective pinning centers to increase the interlayer coupling and reduce the compound anisotropy by:

a. Cation Substitution

It is known that the critical current of these materials can be enhanced by incorporating a high density of extended defects to act as pinning centers for the fluxons [2, 3]. The cation constituents are expected to either weaken the superconducting order parameter and to become normal in the presence of a magnetic field before the rest of the sample or increase the defect density such as dislocation. The defects, such as dislocations, act as pinning centers to prevent the movement of the magnetic fluxoids, thus, enhancing the J_c at high field.

b. Introducing nano-particles to create high density defects $(H/2)\times 10^{11}\text{cm}^{-2}$ with size approaching the superconducting coherence length.

Pinning is optimized when the size of the defect approaches the superconducting coherence length (~2-4 nm for YBCO at temperatures $\leq$ 77 K) and when the area number density of defects is on the order of $(H/2)x10^{11}$ cm^{-2}. Such a high density has been difficult to achieve by material processing methods that maintains a nanosize defect. Introducing nanosized particles is the most effective way to achieving a dispersion of 8 nm-sized nanoparticles and create high density defects.

Achievements:

a. Fabrication and improvement of the performance of HTS-based tapes

We developed a non-vacuum two-step spray compress process for the fabrication of YBCO, BSCCO, and HBCCO thick films. We achieved YBCO thick films with a J_c of $7x10^5$ A/cm^2 at 77 K in self-field and BSCCO thick films with 4.2 K J_c of $5x10^5$ A/cm^2 at zero field and $3x10^5$ A/cm^2 at 8 T. We have studied the influence of a $(Y,Ca)Ba_2Cu_3O_{7-\delta}$ top layer on the critical current of YBCO films and found a ten-fold enhancement of the critical current density at 4.2 K in polycrystalline YBCO films on MgO substrates and that the Ca-doping improves the film alignment in multi-layer configurations.

b. Cation Substitution

We have studied the $(YHO)Ba_2Cu_3O_7$ and $Y(BaNd)_2Cu_3O_7$ systems and compared them with YBCO films. The results are shown in Figs. 1 and 2. The YBCO thin film exhibits a J_c up to $6.8x10^7$ A/cm^2 at 5 K and B_a = 30 mT; and J_c = 1.8 $x10^7$ A/cm^2 at 60 K and B_a = 10.5 mT. These results indicate the high quantity of the film. The cation (HO) substitution in Y site relaxes the preparation condition by being able to deposit the film under a wider temperature range, but enhancement of critical current density was not observed.

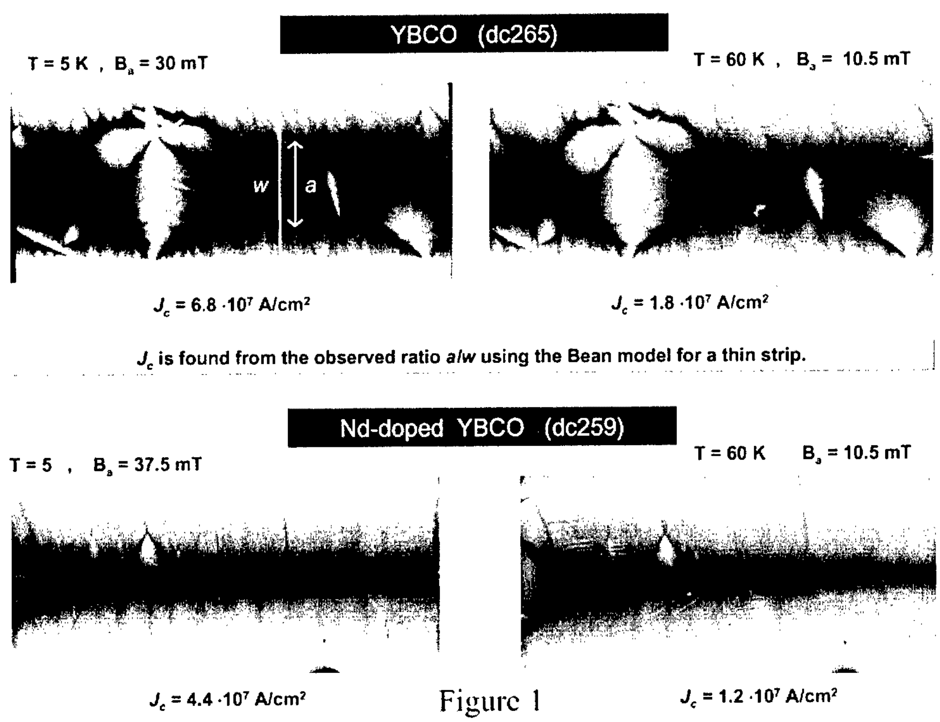

Figure 1

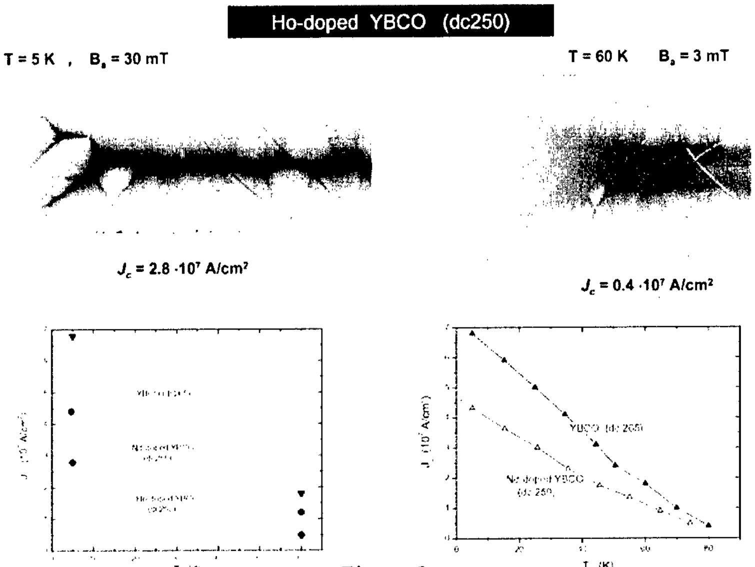

Figure 2

It has been reported that rare-earth substitution at the Ba site in YBCO generates defects that act as an effective "field-induced type" pinning center that enhances the J_c at higher fields for melt-textured and polycrystalline bulk YBCO samples [4, 5]. Our results indicate that at lower temperatures the J_c is almost two times lower than YBCO films. However, the slope of the J_c as a function of temperature is flatter than YBCO and a J_c similar to YBCO above 77 K was achieved.

c. Introducing Nano-particles (This work is in cooperation with ORNL)
Introducing effective pinning centers by nano dots in the superconducting thin films has been reported [6, 7]. However, most reports produced the nano dots by laser ablation or sputtering methods, which are very complicated and high cost approaches. We have successfully applied a simple, non-vacuum, spin-coating process to produce nano dots on the substrate. This method can easily be adapted for practical applications.

Preliminary results indicate a four-fold enhancement in the J_c at 77 K for films with nano-dots made from the metal iridium.

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2 Electroplated Ni Layer on Textured Cu Substrate for Cu-based HTS Coated Conductors

Alternative Cu based coated conductors have been developed where textured Cu is used as the substrate. In general, such substrates have the advantages of easy formation of a sharp cube texture, no ferromagnetic contribution to hysteretic AC losses, low cost compared to nickel or nickel alloy substrates and low resistivity. The primary disadvantage, however, is that Cu has poorer resistance to oxidation than Ni and Ni alloy substrates, especially in an oxygen atmosphere at high temperatures necessary for the fabrication of YBCO superconducting layers. One potential solution for overcoming this problem is to deposit a metal protective layer over the textured Cu substrate to reduce the Cu oxidation rate and protect its diffusion to YBCO. Electroplating has been used for many years to fabricate decorative and protective metallic films. It is non vacuum, low cost, fast and easily scalable, which gives the promise for the production of long length Cu based coated conductor tapes.

Research Project Achievements:

The Cu substrates were mechanically deformed by rolling followed by annealing at temperature 800 °C for 60 minutes. The FWHM values of these substrates were typically found to be 4.2° and 6.5° for out-of-plane and in-plane alignments, respectively. A low cost, non vacuum and easily scalable technique of electroplating was developed for the production of long-length RABiTS-based coated conductor tapes. Smooth, crack-free and continuous 1-4 μm thick electroplated Ni overlayers were deposited on cube textured Cu substrate without any intermediate layers. After high temperature heat treatment, both the Cu substrate and Ni overlayer retain the cube texture and chemical stability. Fig. 3 shows the θ-2θ x-ray scans for 3 μm Ni overlayers electroplated on textured Cu substrate after heat treatment at 750 °C for 30 minutes. The FWHM values of electroplated Ni for in-plane and out-of-plane alignments to be 6.40° and 4.66°, respectively. Sharp cube textured Sm-doped CeO_2 buffers have been grown on Ni plated Cu substrate using pulsed laser deposition with in-plane and out-of-plane FWHM values of 6.50° and 5.25°, respectively. The superconducting quality of this template was tested with YBCO deposition. X-ray studies shown in Fig. 4 indicate that YBCO films have good out-of-plane and in-plane textures with full-width-half-maximum values of 6.5° and 8.1°, respectively.

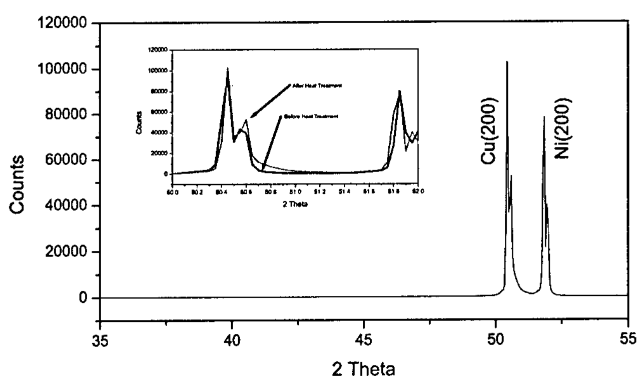

Fig. 3 The θ-2θ x-ray scans for 3μm Ni overlayers electroplated on textured Cu substrate after heat treatment at 750 °C for 30 minutes.

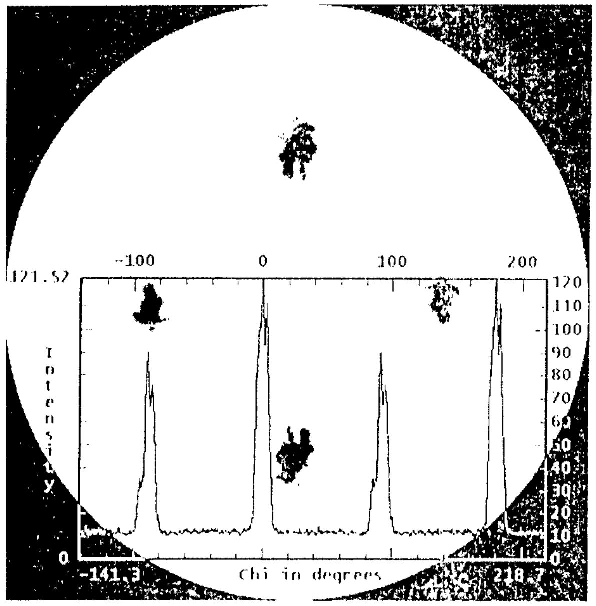

Fig. 4 The YBCO pole figures for the YBCO/CeO2/Ni/Cu coated conductors.

List of Publications

1. R. L. Meng, A. Baikalov, D. Pham, I. A. Rusakova, Y. Y. Sun, J. Cmaidalka, C. Wang, M. N. Iliev and C. W. Chu, "YBCO/YCBCO Multi-Layer Healing Technique for YBCO Coated Conductors," submitted to Proceedings of the 2004 Applied Superconductivity Conference, Jacksonville, Florida, October 3-8, 2004 (October 3, 2004); to be published in IEEE Transactions on Applied Superconductivity.
2. Y.X.Zhou, S. Bhuiyan, H. Fang and K.Salama, "Chemically Coated Buffer Layers Deposited on Rolled Ni Substrates for HTS Coated Conductors" Proceeding of Am. Ceram. Soc. 2003.
3. Y.X.Zhou, L. Sun, X. Chen, P.T.Putman, H. Fang and K.Salama, "Manufacturing of Electroplated Ni Layer on Textured Cu Substrate for Cu-based HTS Coated Conductors" ,Supercond. Sci. & Technol. 18(2004)107.
4. Y.X.Zhou, R. Naguib, H. Fang and K.Salama, "Development of Cube-Textured Ni-W alloy Tapes Using Powder Metallurgy Along with High Energy Ball Milling for HTS Coated Conductors" ,Supercond. Sci. & Technol. 17 (2004)947.
5. Y.X. Zhou, X.Zhang, H. Fang, P.T. Putman and K. Salama, "Development of Single Solution Buffer Layers on Textured Ni Substrate for HTS Coated Conductors" IEEE, transactions on applied superconductivity 2004 (Accepted).

Contributed Presentations:

1. R. L. Meng, D. Pham, Y. Y. Sun, I. A. Rusakova, J. Cmaidalka, A. Baikalov, C. Wang and C. W. Chu, "The YBCO/YCBCO Multi-layer Healing of Weak-Links for YBCO Coated Conductors," Jacksonville, Florida, 2004 Applied Superconductivity Conference, October 3-8, 2004
2. K. Salama, "Development of Coated Conductors for Superconducting Applications", TcSAM, June 23, 2004.

3. K. Salama, "MOD Approach for the Growth of Epitaxial Buffer Layers on Biaxially Textured Ni-W Substrates for YBCO Coated Conductors", Peer Review of Air Force Office of Scientific Research, January, 2004.